Identifying Non-Technical Barriers to Energy Model Sharing and Reuse

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IDENTIFYING NON-TECHNICAL BARRIERS TO ENERGY MODEL SHARING AND REUSE

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ABSTRACT

This paper presents the results of a survey of 306 building professionals investigating the feasibility of reusing design-phase energy models post-design. Most (75%) of the 154 engineers/energy modellers surveyed believed that their models could be used by a third party for commissioning and building operation. Nevertheless, the survey revealed several non-technical challenges associated with model sharing and reuse. In response, this paper provides suggestions to energy modellers, building owners, and software developers for overcoming these challenges and includes references for relevant legal contracts. Keywords: Energy Simulation, Survey, Commissioning, Building Operation, Contracts

INTRODUCTION

During the design-phase of a new or retrofit building, computer energy simulations can be used to compare relative changes in energy use for different design options. Building owners increasingly use these models to demonstrate energy savings for compliance with regulations, such as the UK's Building Regulations Part L or for voluntary green building rating systems such as the US Green Building Council's LEED system. Compliance with a program such as LEED typically requires a detailed energy model with an estimated modelling effort of 120 person-hours for a typical commercial building (Korber-Gonzalez, 2011). However, after the design phase, these costly models are typically ignored. This practice provokes the question; could design-phase models serve other, value-adding purposes?

Calibrated energy models are models of operational buildings for which key simulation inputs such as HVAC schedules have been updated according to actual building use rather than according to assumptions made during design. These models can be valuable for verifying the performance of installed energy conservation measures (IPMVP, 2006). Other possible uses are to normalize the building energy consumption with respect to occupant behaviour and weather for the sake of comparison between buildings (Jensen, 2007) or to help detect and diagnose functional problems in the building (Claridge, 2011).

This paper deals with this last usage, called on-going commissioning. Its premise is that most commercial buildings do not perform optimally with respect to energy use. For example, Liu et al (1994) showed that the energy consumption of commercial buildings could be reduced by about 20% with improved operation and maintenance. Claridge et al (2000) demonstrated, in a study of US academic buildings, that a payback of one to two years could be expected with ongoing-commissioning. In one approach, sometimes called automated fault detection and diagnostics (FDD), a computer periodically compares the metered to predicted performance of a whole building or individual components. If it detects a large discrepancy, for example if equipment fails, the FDD system can then alert the building manager. This FDD approach has been tested (Jacob et al. 2010, Kissock et al. 2002) and there are even initial commercial solutions available based on this research (Katipamula, 2003).

These systems typically use so-called “black-box” models which are based on historical measured energy use of a building with no or limited knowledge of the physical processes in the building. These models, typically multilinear regression or automated neural networks, rely on a limited set of input data and learn to anticipate the energy consumption over time for various conditions such as ambient temperature and day-type (weekday or weekend.) Their main attraction is that they require only a moderate amount of time to construct, (Katipamula, 2003) so that they can be implemented at a relatively low cost. However, they can merely detect whether the building behaves consistently over time under comparable usage and climatic conditions without knowledge of whether the absolute energy use is at all appropriate for that building. To overcome these limitations, an alternative idea is therefore to use a physically based “white-box” model that has sufficient information about a building to gauge its absolute energy performance. A white-box model can potentially help to verify whether a building performs according to its original design intentions. Being based on first principle, it also does not need any training period to function and allows the exploration of 'what if' scenarios for future building retrofits. On the flipside, a white-box model requires significant time/cost to create. The question is whether the required additional modelling effort for white box models can be justified by increased potential energy savings vis-à-vis the use of black box or no models. One possibility to skew this analysis in favour of the white box model is to use an existing design-phase energy model, if available, as a starting point and calibrate it so that it can function as a white box model. Presumably, an owner who already paid for a design-phase energy model has a natural interest in verifying that his/her building operates as designed. For such an owner the natural question would be can the design phase model be turned into a calibrated white box model and at what cost. Design-phase models cannot be immediately functional as white box models because the measured building energy use differs for most buildings from the simulated building performance.

This fact is exemplified in Figure 1 for 98 LEED certified buildings.[1] The figure is based on a dataset of buildings completed from 2000-2006 and for which the New Buildings Institute collected various information including measured and simulated building energy use intensity (EUI) (Turner & Frankel, 2008). If design-phase energy models were perfect predictors of actual energy use, all data points in Figure 1 would lie on the model line. However, the figure shows somewhat discouraging scatter, with an R^2 value of 0.4, thus illustrating the need to calibrate those models before using them for continuous performance monitoring. The results from Figure 1 may not come as a surprise. ASHRAE's standard 189.1 for high performance green buildings, Appendix D1.2, explains that discrepancies between modelled and measured energy use should be expected "due to variations such as occupancy, building operation,... energy use not covered by this procedure..." etc (ANSI/AHRAE/USGBC/IES 2010). On the other hand, it has been shown that carefully calibrated energy simulation models are able to model the annual energy use of commercial buildings to within 5% (Waltz, 2000).

A number of researchers currently work on the technical challenges and work flows of calibrating energy models (Reddy, 2005, Claridge, 2011). However, there are other *non-technical* challenges to reusing design-phase models post-design, and these are the focus of this paper. These challenges include

1 Software used: Stata Release 10. Data set: LEED-NC version 2 certified buildings. Models followed ASHRAE 90.1 App. G protocol. The natural logarithm of each EUI was used to highlight the *relative* rather than the *absolute* error.

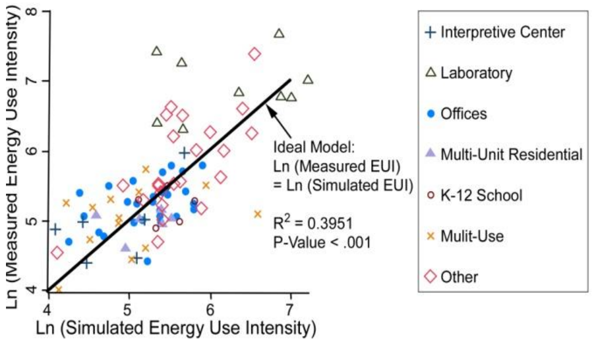

Figure 1: Simulated vs. Measured Energy Use Intensity

the potential unwillingness of modellers to share their digital files. To understand the importance of this topic, consider the history of two other digital file precedents: CAD (Computer Aided Design) and BIM (Building Information Modelling.) Through the 1990's and early 2000's in the United States, CAD file sharing, especially between the design and construction team, was often avoided completely or accompanied by, in the words of the American Institute of Architects (AIA), such "draconian disclaimer notices" (AIA, 2007a, Noble & Heart, 2008) that the recipient sometimes would rather start the drawings from scratch than assume the risk of reuse. As a result, overall industry efficiency suffered. With the advent of modern digital file sharing agreements (for example: AIA, 2007b) the situation has improved. However, problems persist even today when, in theory, BIM offers a platform for architects, engineers, and contractors to contribute to or extract information from one coordinated digital file. Anyone familiar with practice today knows that BIM is seldom used to its fullest capability. Instead, concerns of liability, proper compensation, and other issues, likely of more interest to lawyers and accountants than designers or software developers, often hinder model sharing which, in turn, hinders industry efficiency. These same types of issues could potentially apply to energy models. Therefore, the authors prepared an online survey investigating these and other barriers to energy model sharing and reuse. The results of this survey, along with some possible solutions are presented in the following.

THE SURVEY

An online survey was conducted from July 9th to September 18th 2009. The questionnaire was approved by the Harvard University Standing Committee on the Use of Human Subjects in Research under file number F17883-101. The main emphasis of the survey was to better understand who on the design team owns and obtains access to the energy model of a building, what role the model currently plays during building design, and how the use of the model could be extended to the overall lifetime of a building. Additionally, the survey included questions about BIM, Integrated Project Delivery, and post-occupancy evaluation; however, these topics are outside the scope of this paper. The focus groups for the survey were building owners (preferably informed owners of multiple buildings), architects, HVAC engineers, and energy modellers. The authors primarily used popular email lists such as onebuilding.org to recruit participants.

1 Participants' Background

Responses came from 31 countries across the globe with the majority from the US (60%) and Canada (13%). A total of 306 individuals participated, identifying themselves as 116 energy modellers/energy consultants, 38 design engineers[2], 34 real estate owners, and 118 architects. While these sample quantities may be limited, the survey results can be assumed to be somewhat representative for the community of energy modellers.[3] The responses may be skewed toward a US perspective. However, the modellers/engineers were a slightly more international group, with 54% coming from outside of the US. The real estate owners had a median portfolio size of 160,000 m^2 (1.75 million ft^2), and 75% of them had participated in six or more new construction or retrofit projects in the previous decade. The architects' firms ranged in size from less than 5 employees (26%) to more than 50 employees (47%). The following presents the most relevant survey questions and answers. The complete survey questionnaire is available from the authors.

2 Current Practice

2a Owners: Do you track and benchmark your building energy use? Of the 24 respondents, 62% answered yes. When asked to describe these "energy tracking" procedures, they listed a range of activities. At one extreme, two respondents mentioned nothing more than reviewing utility bills. At the other extreme, a respondent mentioned a National Renewable Energy Laboratory (NREL) 2-year evaluation of their building.

2b Owners: Do you have any commissioning procedures in place to verify that your buildings function as designed? A total of 61% of [23] owners said yes. However, it should be noted that in the write-in description of these procedures only six of the respondents actually described commissioning procedures that exceeded normal construction closeout practices.

2c Architects: Are you currently evaluating the energy performance of your projects? Select all that apply. A total of 100 architects responded as follows: No, not currently because it is too costly [6]. No, not currently because our clients are not interested in the subject [9]. Yes, through the use of rules of thumb and other general sustainable design guidelines [58]. Yes, using *in-house* energy modellers to track the energy performance of our projects *throughout* the design and construction process [33]. Yes, usually through an initial consultation with an *outside* energy consultant at the *beginning* of a project [25]. Yes, usually through an *outside* energy consultant at the *end* of a project to get LEED certification [26]. Yes, we are continuously working with an *outside* energy consultant throughout the design and construction process [34].

2d Architects: How frequently do the results from the energy model directly change your design? A total of 62 architects responded as follows: Always [6], Quite often [33], Occasionally [18], Rarely [5], Never [0].

Cross-referencing the responses from questions 2c and 2d produces interesting results. As shown in Figure 2, the use of in-house energy consultants/ modellers increased, but not significantly, the frequency with which the energy model influenced the design. However, the results indicated that the timing of the interaction with the energy consultants/modellers *was* significant. **The architects utilizing energy consultants/modellers only at the end of their projects for LEED documentation reported that the models impacted their designs significantly less frequently than those using consultants/modellers at the beginning or throughout their projects** (P-value = 0.019). This finding confirms the popular belief in the benefits of earlier design-stage energy modelling.

2e Modellers/Engineers: What software programs are you primarily using and for what task? The 116 respondents listed, among other types of programs, 14 different energy simulation programs.[4] No single energy simulation program was listed by more than roughly 20% of the respondents. This diversity is surprising in comparison to other arenas, such as CAD, in which a few software packages dominate the market.

2f Modellers/Engineers: Please list up to three major problems that you frequently encounter during energy modelling and that you think prevent its more widespread and cost-effective implementation. Example: Interoperability issues between different software packages. Software interoperability issues were the most frequently cited answer, mentioned by 40 of 98 respondents. The wording of the question likely skewed these results. Nevertheless, most respondents elaborated on the difficulty in

2 The "energy modellers/consultants" answered the same questions as the "design engineers," who exhibited both an interest in and knowledge of energy modelling. Therefore, their results are combined here unless otherwise noted.

3 The population of energy modellers is relatively small. There were 1992 individuals subscribed to the onebuilding.org list in May 2010, according to Jason Glazer list manager, and representatives of the overwhelming majority of 'serious' energy modelling firms in the world are subscribed to the list.

4 In 2010 there existed at least 123 whole building energy simulation tools (US DOE). http://apps1.eere.energy.gov/buildings/tools_directory/

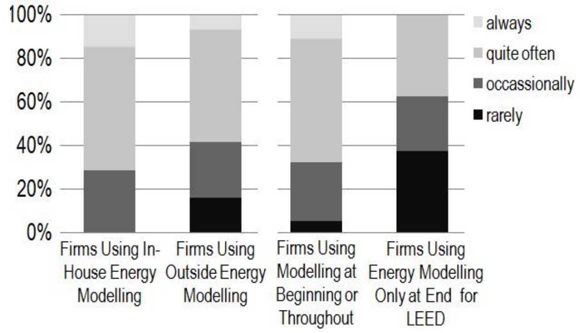

Figure 2: How Frequently the Results from the Energy Model Change the Architect's Design

transferring information between other CAD, BIM, or analysis software and energy modelling programs. Universal file formats, such as gbXML (Green Building Extensible Markup Language www.gbxml.org) and IFC (Industry Foundation Classes www.buildingsmart.com), have been developed to make transfers between software packages possible. However, the general consensus among respondents was that transfer workflows are still troublesome. One can infer from these results that software interoperability between different energy modelling packages, potentially important if models are to be shared, would be likewise difficult.

3 Owner Interest in Using Models

Owners: If properly calibrated, an energy model can help you, the owner, to closely monitor and often substantially lower the energy use of your buildings as well as alert you if parts of your HVAC systems fail or become less efficient over time. To make such use of an energy model you need the help of a trained building modeller. Which of the following choices best describes your reaction to this statement? I might be interested in using energy models to enhance building operations even if it required additional training of one or two of my building services associates [15]. I am, in principle, interested in the use of energy models to enhance building operations but I would prefer to outsource this service [6]. I am *not interested* in this service because my buildings already function properly [2].

The owners surveyed showed an overwhelming positive interest, 91% [21], in utilizing energy models in ongoing-commissioning, at least in the best-case scenario described. These responses indicated that -at least in the limited sample of owners surveyed- there exist a group of owners potentially interested in providing some form of compensation for in-house or outsourced services to use energy models for ongoing-commissioning. However, since this strategy is relatively new, these respondents cannot be expected to fully appreciate the cost/complexity of implementing this strategy.

4 Feasibility of Model Reuse

Given that a potential commercial interest in continuous commissioning via design-phase energy models has been established, the focus now shifts to the providers of these models.

4a Modellers/Engineers: Do you think that your energy models could - in principle - be used by the owner or another member of the design team during commissioning and operation? As illustrated in Figure 3, the majority [88 of 118] responded with 'yes'. For the authors the fact that **75% of the participating energy modellers - who constituted a sizeable portion of the overall industry - indicated that they believe that their models can be used in commissioning and operation** was the central outcome of this survey.

4b Why could the model not be used by another party? Example: The model is too specific or complicated for somebody else's use. The remaining 30 respondents who did not believe their energy models could be feasibly reused were asked this question. They provided the write-in responses summarized in Figure 3. Some notable quotes from these respondents included: *"[I] want to preserve my competitive edge: a restaurant owner [doesn't] give away his recipes." "[Another] party could change parameters and blame us for results saying it was 'our model.' "Everyone follows his own way to set up the energy models. It will consume more time to understand [an]others' model than to build a new one."*

4c Would you be willing to adapt your energy model, potentially even change the simulation program that you are normally using, if the owner made this a firm contract requirement? The respondents who did not believe that their energy models feasibly could be reused were given this follow-up question. They [28 of 30] responded as follows: I would not adapt my model [4]. I would *adapt* and share my model under the conditions specified below [question 5d] if the owner is an important client [12]. I *would change the simulation program* and share my model under the conditions specified below [question 5d] if the owner is an important client [13]. I would *not* change the simulation program that I use, because my internal workflows are too closely linked to it [6]. Other [6]. Owners should note that only 14% of all modellers [4] indicated that they would *not* adapt their model in any way.

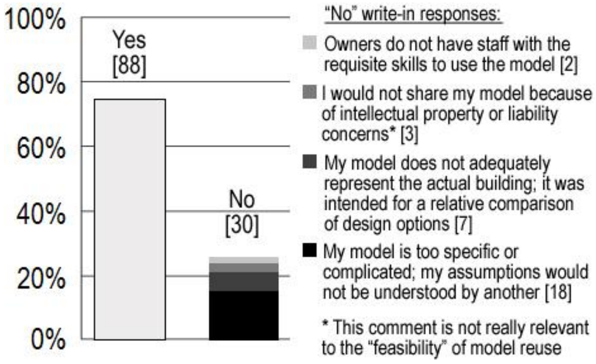

Figure 3: Feasibility of Model Reuse

5 Willingness to Share Models

The previous sections investigated the interest in, and the perceived *technical feasibility* of, reusing design-phase energy models. Next, the survey investigated the willingness of professionals to *share* these models. The following sections first probe digital file sharing practices in general and then the willingness to share their energy models in particular.

5a Modellers/Engineers: What are your typical project deliverables? Select all that apply. The 114 respondents answered as follows: Report specifying simulation assumptions, results and design recommendations [108], Suggested design alterations [91], Electronic copies of the simulation files [33], Product specifications [28].

5b Have you ever provided a digital model of any kind to another member of the design team including the owner? Owners: Have you ever received a digital model of any kind...? Modellers/Engineers: 55% [65] responded 'yes'. Architects: 85% [81] responded 'yes'. Owners 72% [21] responded 'yes'. These responses indicate that the architects and owners were more involved in file sharing than the modellers/engineers. There could be a number of reasons for this, e.g. clients may not request a copy of the energy model, because they do not perceive a use for it yet.

5c If yes, what type of model (CAD, BIM, energy) and what did the other party do with it? Architects [95] and engineers/modellers [118] wrote-in responses mentioning: BIM [42], CAD [28], preliminary design models [10], and energy models [5]. Two write-in responses described the use of energy models beyond the design phase: for "M&V [measurement and verification] implementation" and "operational follow-up". Importantly, these responses show that the use of design-phase energy models post-construction exists in the realm of practicing professionals, not just academic researchers.

5d For those Modellers/Engineers who thought their model could be used by the owner or were willing to adapt their model: Under what circumstances would you be willing to share your energy models with the owner or the rest of the design team? Select all that apply. The responses are shown in Figure 4. By

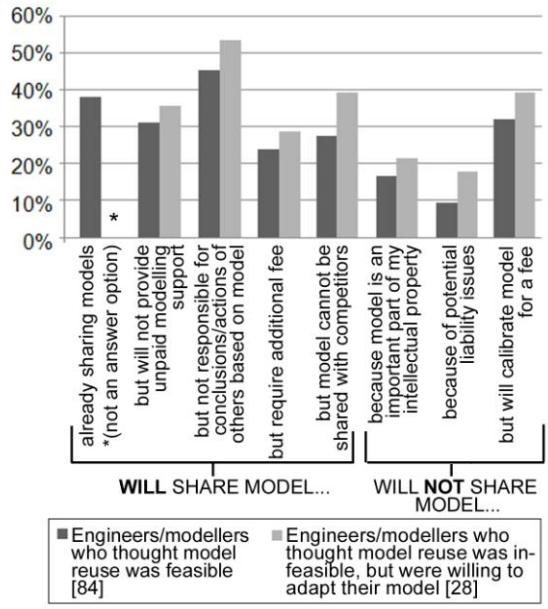

Figure 4 "Under what circumstances would you be willing to share your energy model?"

offering the multiple-choice answers shown, the authors strove to understand the stipulations surrounding the professionals' willingness to share, as well as any reasons for their unwillingness to share, their energy models. As Figure shows, intellectual property issues, protecting trade secrets, liability concerns, and appropriate compensation were all concerns. Of those modellers/engineers who believed that their model could be feasibly reused by the owner, 84 answered this question. Of those, 80% indicated they would not share their models with the owner or design team OR they would require certain stipulations for sharing. Meanwhile, 20% [17] indicated they are already sharing their models, and 24% [20] would request an additional fee for preparing the model for sharing. Additional write-in responses are summarized below:

- One respondent suggested a hand-off meeting as a way to familiarize the next user with the peculiarities of the model.
- Another explained that his/her willingness to share the model depended on who might be using it: *"high level interaction is welcomed, but not training someone to use our model."*
- Two respondents disagreed over the current capabilities of owners: *"I like the concept of an owner that would [use] our model after the construction work.... Owners with the requisite knowledge/skill set and interest are hard to come by however."* In contrast, *"I am involved in a lot of Energy Performance Contracting where the energy model is scrutinized by the Owner and Utility for establishing economic models, baseline energy use and fee. I think that there is a lot of newly developed sophistication in the client's review of my work product that in the near future,*

the owner's knowledge will equal that of the energy modeller...."

- Five respondents described their liability or intellectual property concerns and stipulations.

5e For those who indicated they would request an additional fee for sharing their energy model: How high would that additional modelling fee roughly be? Example: 25% of the regularly paid fee for service. A total of 28 Modellers/Engineers provided write-in responses. The answers varied greatly. The range of answers included both *"hourly"* and "*5-50% of the modelling fee."* Generally, the answers gravitated around 20% of the energy-modelling fee. Some of the respondents qualified their answers by explaining that the fee would be necessary to pay for additional work such as gathering background documentation or switching the model to a more user friendly format.

6 Model Ownership

Owner: Who, in your opinion, owns the CAD, BIM and energy models that you commission? Architects and Modellers/Engineers: Who, in your opinion, owns the energy model? As illustrated in Figure 5, this question sparked a great deal of disagreement. Surprisingly, each of the professional groups surveyed predominantly believed that, in the absence of specific contract language, they themselves owned the energy model. Respondents offered additional write-in responses that confirmed the state of confusion, as some respondents stated that whoever built the model owns it [5], while others stated that whoever paid for the work owns it [12].[5]

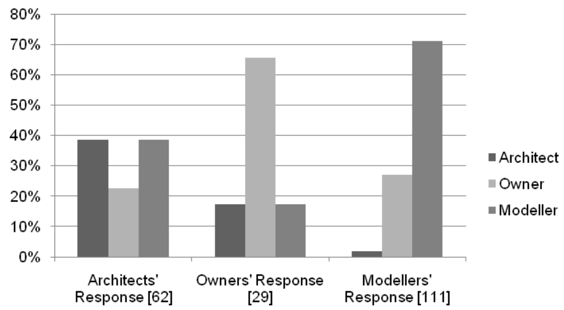

Figure 5: Responses to the Question, "Who, in your opinion, owns the energy model?"

DISCUSSION

Local regulations and customs may affect model sharing and reuse practices. For example, in the US most models are built to demonstrate compliance with rebate programs or the voluntary LEED rating system. In contrast, other countries, such as the UK, Canada, and other European states increasingly require some level of energy simulation to demonstrate building code compliance. Hamza & Greenwood (2009) suggested that in the UK models are increasingly shared as part of tendering documents in response to Building Regulations Part L.[6] However, in the survey presented here, the sample sizes were too small to identify any statistically significant differences between responses from various locales.

Advice to Energy Modellers

Creating a model that would eventually be used for commissioning and operations could be a new business opportunity if one could overcome certain barriers. As identified by the survey results, the first is the issue of *"Human Interoperability",* or the ability of the future user to understand the original author's work. Documenting assumptions and using universal modelling standards could help. Such standards could be promoted through organized programs such as ASHRAE/IBPSA/IESNA's Building Energy Modelling Professional certification. Another solution could be the establishment of longer-term modelling & commissioning partnerships allowing individuals to develop familiarity with each other's work.

Intellectual Property: The survey results revealed confusion over model ownership. In the US at least, it is no wonder that this confusion exists. Although the US Copyright Act (Title 17 of the US Code, 1976) and the Architectural Works Copyright Protection Act (1990) govern this issue, both laws show a lack of sensitivity to post-digital age works (Noble, 2010).[7] In an interview, Noble explained that the design and construction industry usually interprets these laws to mean that the creator of content owns that content. However, project teams often handle specific situations by written contract. Nevertheless, unlike an author or musician who receives royalties for each copy sold, building modellers usually make one-of-a-kind products and are paid for their *services,* meaning they receive payment for their work regardless of ownership. Therefore, for some modellers, the bigger issue of concern is that of protecting trade secrets.

Trade Secrets: The survey responses revealed a fear among some expert energy modellers of losing their competitive edge if beginners were to gain access to their custom tools and modelling techniques. Therefore, some modellers desire protection against their work falling into the hands of the competition. Although not foolproof, a non-disclosure agreement (NDA) can help. A number of free NDA templates are readily available via internet search. More specific to the building industry, the American Institute of Architects documents E201 and C106 include a clause limiting the disclosure of

5 One may expect that the discrepancies over model ownership may be related to a difference in local laws; however, these responses showed no correlation to the respondent's location.

6 At the high extreme, 68% of modellers from Canada [11 of 16] indicated they already share their energy models.

7 Unfortunately, an investigation into legal precedents outside the US is outside the scope of this paper.

confidential information to *"those who need to know the content of the Confidential Information in order to perform services... solely and exclusively for the Project..."* (2007b).

Liability: The survey responses also identified liability as a perceived barrier to digital model sharing. Some respondents described fears of being held accountable for changes made to the model by others or for decisions made based on the model outside of its original intent. For concerned modellers, contract language indemnifying professionals against certain claims, is easy to find. For example, the ConsensusDOCS BIM Addendum (2008) states, "*Each Party shall be responsible for any Contribution that it makes to a Model.... No Party involved in creating a Model shall be responsible for costs, expenses, liabilities, or damages which may result from use of its Model beyond the uses set forth in this [document]."* To avoid exaggerating the concerns over intellectual property, trade secrets, and liability, one should remember that only a minority of respondents mentioned these issues.

Advice to Software Developers

If energy models are to be shared, and if the diversity of simulation tools mentioned in the survey responses continues, the further maturation of universal file formats and transfer workflows will be vital. In addition, if the model is meant to be available for use in the future, ideally this format will evolve with backwards compatibility. Meanwhile, software controls could help liability-shy professionals like some of the survey respondents. These controls could not only lock portions of the model, as mentioned, but also log changes. In a paper on digital design and construction files, Ashcroft and Hurtado (2009) explained that, because of the ability to log changes, *"concerns about liability for stealing or modifying data are **not** the monsters they are being made out to be."* In addition, access controls could be used to hide proprietary modelling information from future users. These same controls could help simplify the model interface, e.g. by giving the building manager access only to certain parts of the model. Alternatively, this could be achieved with specialized on-going-commissioning software able to read-in the energy model and provide a simplified and consistent interface for the building operations team. This would help solve some of the human interoperability issues also identified in the survey responses. Software that makes it easier to document modelling assumptions also would be helpful in this regard.

Advice to Owners

Most building owners likely will not be able to afford a specialized employee on-staff to make use of a building energy model. However, one can envision a future scenario with a proliferation of outsourced building monitoring services where individual managers would monitor several buildings remotely. In this way, building managers could become more specialized perhaps making the use of energy models in operations more realistic.

Building owners interested in utilizing design-phase energy models post-design should take measures to ensure that the delivered product meets their needs. First, the prudent owner may wish to establish a *license* for the intended model uses. The AIA 2007a and the other AIA and ConsensusDOCS references listed herein include example licensure language for other types of digital files. Second, the final model would need to be updated with any building changes that occurred throughout the design and construction process. Third, the survey results highlighted the importance of establishing human interoperability. Therefore, owners wishing to reuse energy models should require the documentation and submission of modelling assumptions. These owners should also request that the modeller organize and label the model for ease of future use. In addition, scheduling a hand-off meeting may be beneficial to familiarize the next user with the peculiarities of the model. Fourth, the owner should ensure that the model will be delivered in the desired software format. As the survey results indicated, modellers today use a wide array of software packages. It is highly unlikely that the owner's team will be familiar with all of them. Finally, since all of the tasks described above require effort on the part of the modeller that is likely outside the normal project modelling scope, the owner should expect to pay an additional fee for these services. The responses to question 5e can give the owner a starting point for estimating this cost. Most importantly, the owner should establish these end-goals up-front, otherwise important opportunities may be missed. Although not written specifically for energy models, the State of Ohio Building Information Modeling Protocol (2010) offers a precedent for owners wishing to define their model needs. This document covers topics such as defining end-uses and specifying levels of model detail and accuracy. Fortunately for owners, almost half of the modellers/engineers surveyed [12 of 28] would be willing to adapt their model if an important owner made it a contract requirement.

Future Research

This paper dealt with the *non-technical* challenges in design-phase energy model reuse. One survey response summarized the *technical* challenge: Energy modelling "*is a comparative exercise, not a predictive exercise. Although energy models can be converted to more predictive types of models by calibrating them against a building's actual historical energy usage, this is a whole other exercise that is potentially even more involved than the* *original design phase type energy modelling exercise itself."* The authors agree with that generalization of today's models. However, the important question is not whether calibration is more difficult than creation of the original model. The question to be answered is whether the benefit of reusing the model can outweigh the cost of preparing it for reuse. The poor performance of our commercial buildings leaves a large margin for improvement. Carefully documented case studies are now required to quantify the financial and energy benefits of using calibrated energy models for operational and financial decision-making.

CONCLUSION

This paper presented results from an online survey on the potential use of calibrated design-phase energy models in building commissioning and operation. The 306 responses reflected a sizable interest, especially in the energy modelling community, in this topic. Considering the enormous energy savings potential of ongoing-commissioning, the question investigated was whether utilizing the energy model in these processes is technically feasible and whether professionals are willing to engage in the process. The survey results indicated that 75% of modellers/engineers believed it was, in principle, feasible with their models. Furthermore, most were willing to share their digital models, especially when protected with a few simple contract stipulations. Of course design-phase energy models have limitations, and technical challenges surround model calibration and reuse. Nevertheless, energy simulation is a powerful and relatively young tool, and the frontiers of its utility deserve more exploration.

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